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Method for Analysis of Objects in Microlithography

Cross-Reference to Related Applications

The present patent application is a nationalization of International Application No. PCT/EP2004/007267, filed July 3, 2004, which is based on, and claims priority from, German Application No. DE 103 23 059, filed July 11, 2003, both of which are incorporated herein by reference in their entireties.

Background of the Invention

Field of the Invention

This invention relates to a method for analysis of objects in microlithography by means of an aerial image measurement system (AIMS).

Description of Related Art

Optical imaging systems can frequently be described as transfer chains with optical transfer behavior that is described by the transfer behavior of the individual elements. The transfer behavior manifests itself in resolution capacity and is generally described by the PSF: point spread function and/or spectrally by the OTF: optical transfer function. These topics are discussed in the following references: M. Born, et al., "Principles of Optics" (Cambridge University Press, 1999); J.W. Goodmann,

"Introduction to Fourier Optics" (McGraw Hill Book Co. Ltd., 2000); T.L. Williams, The Optical Transfer Function of Imaging Systems," Publisher: Institute of Physics (1999); and G.D. Boreman "Modulation Transfer Function in Optical and Electro-Optical Systems" (Tutorial Texts in Optical Engineering, Vol. TT52), Publisher: SPIE – The International Society of Optical Engineering (2001).

Normally, the optical transfer behavior of the individual elements is largely determined by the technical limiting conditions and is variable within limits. On the other hand, generally a defined transfer behavior is required for use in measuring technology. If the given limiting conditions are too restrictive, the desired system transfer behavior can no longer be achieved to the required extent. Consequences may include low contrast and low-resolution capacity and the occurrence of imaging errors.

The basic requirement of an AIMS (aerial imaging measurement system) consists of simulating the OTF of a photolithography stepper or scanner as well as possible. A deviation of the OTF leads to errors in the measuring results and their evaluation. Usually, in this case, the first magnification stage is laid out so that its OTF simulates the stepper OTF, while the resolution capacity of the following elements is selected so that it is high

enough that there will only be a negligible negative effect on the system OTF. However, in practice the technical and/or financial limiting conditions limit the correlation with the stepper OTF that can be achieved.

Other references of interest when considering the present invention are E.Hecht, "Optik [Optics]" (Oldenbourg Verlag, Munich, Vienna, 2001); LaFontaine,etal., "Submicron soft X-ray fluorescence imaging," Appl. Phys. Lett. 282 B, 1995; US Patent 5,498,923, LaFontaine,etal. "Fluoresence [sic] Imaging"; and US Patent 6,002,740 12/99 Cerrina, et al., "Method and apparatus for x-ray and extreme ultraviolet inspection of lithography masks and other objects"

Brief Summary of The Invention

The present invention relates to a method for analysis of an object in microlithography. The steps of the method include providing an aerial image measurement system (AIMS) that consists of at least two imaging steps; detecting the image output of the AIMS; and employing a correction filter to correct the detected image with respect to the transfer behavior of the second or other imaging steps. An AIMS apparatus to carry out the method is also defined.

The inventive method further comprises the step of illuminating the object with incident or transmitted light. In a preferred use, the object may be a mask for manufacturing semiconductors.

The image output contains output variables and the correction by the correction filter is carried out in such a way that the corrected output variables of the image correspond to a photolithography stepper or scanner.

In the inventive method, the correction is carried out by an involution and measured or calculated correction values are used for the correction.

To implement the method, the correction is carried out using an electronic circuit by means of an analog or digital filter or an algorithmic correction by means of software in a digital computer.

Detailed Description of the Invention

In describing preferred embodiments of the present invention illustrated in the drawings, specific terminology is employed for the sake of clarity. However, the invention is not intended to be limited to the specific terminology so selected, and it is to be understood that each specific element includes all technical equivalents

that operate in a similar manner to accomplish a similar purpose.

The problem described above is solved according to the present invention in that the output variables of the AIMS system (i.e. aerial images) are corrected with respect to the transfer behavior in an additional processing step so that they correspond to the corrected output variables of the image of a photolithography stepper/scanner with the desired system OTF.

In particular, the following are prerequisites of a favorable outcome:

- that the output variable is a discrete or analog electrical signal or a corresponding digital data set (e.g., the pixel values of a CCD array detector);
- that the desired transfer function (with the OTF: G_{soll}) is already specified by at least one of the transfer elements; and
- that the resolution capacity of the interfering elements ($G_{stör}$) is higher than that of the desired corrected system.

According to the invention, the correction consists of a filtering of the output variable, at which the percentage of the interfering transfer elements in the transfer

behavior is compensated. Possible technical realizations include:

- Electronic circuitry (analog or discrete filter); and
- Algorithmic correction using software in a digital computer (µC, PC, DSP, etc.)

In the following discussion of the present invention, spatially-dependent variables are indicated with lower case letters and their respective Fourier transforms with capital letters. An example that can be named here is the PSF (designation: g(x, y)) and its Fourier transform, OTF (designation ($G(f_x, fy)$).

If the transfer behavior can be described with adequate approximation by a linear system with N elements, the OTF of the system results as a product of the OTFs of the individual transfer elements and the PSF of the system as a convolution product of the PSFs of the individual elements. Generally, it is true that the OTF is the spectrum of the PSF, i.e., its Fourier transform. Accordingly, with a two-dimensional image, the OTF of the system is:

$$G_{System}(f_x,f_y) = G_1(f_x,f_y) \cdot G_2(f_x,f_y) \cdot \ldots \cdot G_N(f_x,f_y) = G_{Soll}(f_x,f_y) \cdot G_{Stör}(f_x,f_y) \quad (1.1)$$

i.e., $G_{Stör}(f_x,f_y) = G_2(f_x,f_y) \cdot \ldots \cdot G_N(f_x,f_y)$

and/or the PSF of the system

$$g_{System}(x,y) = g_1(x,y) * g_2(x,y) * \ldots * g_N(x,y) = g_{Soll}(x,y) * g_{Stör}(x,y)$$

i.e., $g_{Stör}(x,y) = g_2(x,y) * \ldots * g_N(x,y)$

where "*" is the convolution operator. Under the condition that

$$G_{Stör}(f_x,f_y) \neq 0 \quad \text{for all} \quad (f_x,f_y), \quad \text{in which} \quad G_{Soll}(f_x,f_y) \neq 0,$$

the correction filter can be specified as

$$G_{Filter}(f_x,f_y) = [G_{Stör}(f_x,f_y)]^{-1} \quad \text{for all } (f_x,f_y) \text{ in which } G_{Stör}(f_x,f_y) \neq 0, \text{ and}$$

$$G_{Filter}(f_x,f_y) = c \quad \text{otherwise,}$$

with c being any constant. Thus, the filtering theoretically supplies:

$$G_{System}(f_x,f_y) \cdot G_{Filter}(f_x,f_y) = G_{Soll}(f_x,f_y)$$

The filtering can also be carried out as a convolution in the local area:

$$g_{System}(x,y) * g_{Filter}(x,y) = g_{Soll}(x,y)$$

with the filter function

$$g_{Filter}(x,y) = FT^{-1}\{ G_{Filter}(f_x,f_y) \}.$$

$FT^{1}\{\ldots\}$ is the (inverse) Fourier transformation.

In addition to the above mentioned filter function, other functions are also conceivable that do not change the overall transfer behavior, but possibly have better properties, e.g., with respect to noise. Example:

$$G_{Filter}(f_x,f_y) = [G_{Stör}(f_x,f_y)]^{-1} \text{ for all } (f_x,f_y) \text{ in which } G_{Soll}(f_x,f_y) \cdot G_{Stör}(f_x,f_y) \neq 0,$$

and

$$G_{Filter}(f_x,f_y) = 0 \text{ otherwise.}$$

The procedure described applies analogously for one-dimensional or multi-dimensional images. Besides that, it is conceivable in principle to select a spectral representation that is not based on the Fourier transformation, e.g., the Z transformation.

In actual imaging systems, the OTF varies more or less over the image area. Variations of this type can be taken into consideration approximately in that the corresponding filter functions are set up for several suitably selected partial ranges and the results of the associated filtering are superimposed with weighting.

Figure 1 shows the inventive principle schematically.

The imaging system for an object that is characterized by an object intensity i_o (x,y) consists of N steps G_1 - G_N, each of which is characterized by a transfer function.

The image that develops, characterized by a signal distribution s(x,y) is corrected using a correction filter, in that an involution occurs for the steps G_2 - G_N of the imaging system.

The result is a corrected image with an image signal distribution $s_k(x,y)$.

In the following, a system will be described as an embodiment example (see Fig. 2) divided into two imaging steps that correspond to the transfer functions G_1 and G_2 in Fig. 1.

The imaging principle (without an EUV illumination unit) of a two-step EUV-VIS-AIMS (aerial imaging measurement system) is shown for testing a mask for semiconductor manufacturing. The illumination can occur using incident light, as here with the EUV illumination, but can also occur using transmitted light.

The object (in this case a mask structure) is imaged on a scintillator using an EUV lens (intermediate image) that converts the EUV wave length into visible light. Using the subsequent VIS optics, the intermediate image is transferred to a CCD camera.

In it $i_0(x,y)$: object intensity

$i_1(x,y)$: output intensity from step 1 (intermediate image)

$s(x,y)$: measured image signal (output variable from step 2)

In the case of the above mentioned AIMS

$$G_{AIMS}(f_x,f_y) = G_{System}(f_x,f_y) = G_1(f_x,f_y) \cdot G_2(f_x,f_y)$$

with

$$G_{Soll}(f_x,f_y) = G_1(f_x,f_y) = G_{Stepper}(f_x,f_y)$$

(Step 1)

and

$$G_{Stör}(f_x,f_y) = G_2(f_x,f_y)$$

(This step 2 can be composed, e.g., of a percentage of the VIS optics and a percentage of the CCD camera).

$G_1(f_x,f_y)$ is the OTF of the first magnification step that is used to simulate the transfer behavior of a stepper. $G_2(f_x,f_y)$ combines the OTF of the following steps, e.g., remagnification step(s), image converter layers, CCD array detector, etc.

The image by step 2 can be represented by a convolution product:

$$s(x,y) = g_2(x,y) * i_1(x,y)$$

In the equivalent, the image spectrum $S(f_x,f_y)$ can be represented as a product:

$$S(f_x,f_y) = G_2(f_x,f_y) \cdot I_1(f_x,f_y)$$

In this, $g_2(x,y)$ is the impulse response and $G_2(f_x,f_y)$ is the transfer function from step 2. The resolution capacity of step 2 is greater than that of step 1. In other words: the upper limit frequency of step 2 is greater than that of step 1.

This means $|G_2(f_x,f_y)| > 0$ for all points (f_x,f_y) below the upper limit frequency of step 1 (possibly with the exception of individual points (f_x,f_y) in which $|G_2(f_x,f_y)| = 0$ (?))

$g_2(x,y)$ or $G_2(f_x,f_y)$ are adequately known numerically, whether by measurement or calculation on the basis of the device parameters. According to the invention, the intensity $i_1(x,y)$ is reconstructed from $s(x,y)$.

<u>Examples for Determining The Transfer Function of Systems</u>

In a concrete computational example, for an ideal, i.e., image-error-free, incoherent image with circular aperture, the distribution of the radiation intensity in the image plane s(x,y) results by convolution of the radiation intensity distribution in the object plane $i_0(x,y)$ and the standardized spot obliteration function g_i:

$$g_i(x,y)=\left[\frac{2\cdot J_1(\frac{\pi\cdot NA\cdot r}{\lambda})}{\frac{\pi\cdot NA\cdot r}{\lambda}}\right]^2 \quad \text{, where} \quad r=\sqrt{x^2+y^2}$$

(where, numerical aperture λ is the wave length and J_1 is the first-order Bessel function).

The associated OTF G1 of this ideal incoherent image,

$$G_i(f_x,f_y) = \begin{cases} \frac{2}{\pi}\left[\arccos\left(\frac{\lambda\cdot\rho}{2NA}\right) - \frac{\lambda\cdot\rho}{2NA}\sqrt{1-\left(\frac{\lambda\cdot\rho}{2NA}\right)^2}\,\right] & \text{for} \quad |\rho|\le 2NA/\lambda \\ 0 & \text{for} \quad |\rho|>2NA/\lambda \end{cases}$$

$$\text{with} \qquad \rho=\sqrt{f_x^{\,2}+f_y^{\,2}}$$

Thus, the correction filter of an ideal incoherent image results as   for all (f_x,f_y) in which   and

$$G_{Filter}(f_x,f_y) = [G_i(f_x,f_y)]^{-1} \quad \text{für alle } (f_x,f_y) \text{ bei denen } G_i(f_x,f_y) \ne 0\text{, und}$$

$$G_{Filter}(f_x,f_y) = 0 \qquad \text{otherwise.}$$

Image errors can be detected, e.g., by multiplication of the incoherent OTF with a phase term $e^{i\phi(fx,fy)}$.

In the reference mentioned above and , calculations for other systems, e.g., the ideal incoherent image with rectangular aperture, image converter layers, CCD camera arrays, multi-channel plates, etc., are known.

Various methods were developed for measuring the transfer function, see e.g., T. L. Williams; G.D. Boreman; and H. Naumann, mentioned above; along with D. Murata [Editor] "Ein Apparat zur Messung von Übertragungsfunktionen optischer Systeme [A Device for Measuring Transfer Functions of Optical Systems]," Optik 17 (1960); K.-J. Rosenbruch, K. Rosenhauer: "Messung der optischen Übertragungsfunktionen nach Amplitude und Phase mit einem halbautomatischen Analysator [Measuring Optical Transfer Functions according to Amplitude and Phase with a Semi-automatic Analysis Device]," Optik 21 (1964); and A. Bigelmaier, et al. "Ein Gerät zur Messung der Übertragungsfunktionen und Spaltbilder von Photoobjectiven [A Device for Measuring the Transfer Functions and Slit Images of Photo Lenses]," Optik 26 (1967/68).

It should be noted that the transfer function of a system or partial system depends e.g., on the wave length and the numerical aperture. Either the transfer function

can be measured for all the system settings used or the transfer function of one (or more) system setting(s) can be extrapolated to other system settings.

A solution to the problem can be implemented through compensation of the impulse response $g_2(x,y)$. A mathematical implementation involves the following:

- Compensation in the spectral range:

1. Fourier transformation: $S(f_x,f_y) = F\{s(x,y)\}$

2. Division by $G_2(f_x,f_y)$: $S'(f_x,f_y) = S(f_x,f_y) / G_2(f_x,f_y)$

3. Reverse transformation: $s_k(x,y) = F^{-1}\{S'(f_x,f_y)\}$

An unfolding in the local area is also possible using an iterative algorithm.

Under consideration of a magnification M at step 2, the coordinate values i_1 change to i_1'

with $i_2(x,y) = g_2(x,y) * i_1'(x,y)$,

and/or

with $I_2(f_x,f_y) = G_2(f_x,f_y) \cdot I_1'(f_x,f_y)$,

$i_1'(x,y) = i_1(x/M,y/M)$

$I_1'(f_x,f_y) = |M| \cdot I_1(M \cdot f_x, M \cdot f_y)$

(Fourier transformation)

Step 2 (Figure 2) itself is to be seen as a combined system. Step 2 must necessarily contain a wave-optical partial system. In the simplest case, it consists only of the detector (CCD array, or the like). Mathematically, the imaging by step 2 behaves analogously to an incoherent optical image, in which the initial intensity occurs due to convolution of the inherent intensity with the PSF.

An example of the present invention involves compensation of the impulse response $g_2(x,y)$ by correction with a calculated filter (See Figures 3-5). Figure 3 shows the calculated cross section of an object structure intensity $i_0(x,y)$ (3 lines with a width in nm and distance in nm) as a function of the location, as well as the associated image intensities of the first image step $i_1(x,y)$, of the overall system $s(x,y)$ and of the corrected system $s_k(x,y)$, whereby the following image parameters were used: wave length, numerical aperture, signal. An ideal VIS lens was assumed as the interfering element corresponding to the second image stage.

In Figure 4, it can be seen clearly that the intensities of the first imaging step (target) correlate very well with the intensities of the corrected system. Figure 4 shows the absolute-value spectra, associated with Figure 4, of the OTF of the first imaging step $G_1(f_x,f_y)$, of

the second imaging step $G_2(f_x,f_y)$, of the overall system $G_{AIMS}(f_x,f_y) = G_1(f_x,f_y) \bullet G_2(f_x,f_y)$ and of the corrected system $G_K(f_x,f_y)$. It can be clearly seen here, as well, that the absolute-value spectrum of the OTF of the first imaging step (target) correlates very well with that of the corrected system.

Figure 5 shows the absolute value spectrum, associated with Figures 4 and 5, of the correction filter $G_{Filter}(f_x,f_y) = 1/G_2(f_x,f_y)$.

The present invention provides several advantages:

1) Lower resolution capacity adequate for subsequent interfering elements, e.g.,

a) Smaller numerical aperture of the VIS optics of the above mentioned embodiment example, or

b) Larger wave length of the VIS optics of the above mentioned embodiment example adequate, and

c) With the EUV/VIS solution, no index adaptation between scintillator and VIS optics is necessary in order to emulate the stepper imaging using AIMS (This is discussed in the following references: LaFontaine, et al., "Submicron soft X-ray fluorescence imaging," Appl. Phys. Lett. 282 B, 1995oo; and US Patent 5,498,923, LaFontaine, et al.);

2) Simpler technical implementation and thus more cost-effective;

3) CCD with higher pixels or binning can be used => lower noise with shorter time => higher throughput due to shorter illumination time; and

4.) Overall magnification can be selected lower => higher throughput due to larger image field.

An AIMS system for carrying out the inventive method includes the following components. A first imaging device consisting of one of the following: an EUV imaging optics with mirrors, especially Schwarzschild spherical or aspherical lenses; an EUV imaging optics with zone plates; an X-ray imaging optics with mirrors, especially Schwarzschild spherical or aspherical lenses; an X-ray imaging optics with zone plates and/or UV imaging optics with diffractive optics (lenses, beam splitters, prisms, grids, etc.).

The AIMS systems also includes at least one second imaging system which may be implemented through UV imaging optics with diffractive optics (lenses, beam splitters, prisms, grids, etc.); VIS imaging optics with diffractive optics (lenses, beam splitters, prisms, grids, etc.); an electron microscope (PEEM photoelectron microscope); an image converter consisting of an EUV/VIS scintillator, an EUV/UV scintillator, an X-ray/VIS scintillator, an X-ray/UV scintillator, a UV/VIS scintillator, and/or a photocathode.

The photocathode can be implemented by a device that converts photons (X-ray, EUV, and UV) into electrons, by fiber optics, camera, micro-lens array on camera or scintillator, and/or amplifier elements (multi-channel plate).

It is to be understood that the present invention is not limited to the illustrated embodiments described herein. Modifications and variations of the above-described embodiments of the present invention are possible, as appreciated by those skilled in the art in light of the above teachings. It is therefore to be understood that, within the scope of the appended claims and their equivalents, the invention may be practiced otherwise than as specifically described.